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September 26, 1986

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DIVISION OF
OIL, GAS & MINING

RANDY HARDIN
MINING ENGINEER
DIVISION OF OIL, GAS AND MINING
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SALT LAKE CITY UT 84180

Dear Randy:

Please find enclosed a copy of the Slope Stability Study performed on the area above our Cottonwood Pit. In addition, I have included a map of our permit area.

Please feel free to give me a call if you have any questions.

Sincerely,

Lance Jackson
Mining Engineer

Enclosures

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SUMMARY

The stability of the Canyon Cove landslide has been investigated. A complete review of landslide data including previous mining, geology, groundwater, rock mass strength and seismic was made. The cause of the landslide was evaluated and the displacement of portions of the hill was analyzed in depth. Stability analyses including [a] a landslide back-analysis, [b] an analysis of future stability and [c] a run-out analysis were undertaken. A summary of the study results is as follows:

1 - The landslide will likely continue to displace.

2 - It is estimated that catastrophic failure has a 10% probability if future groundwater conditions are similar to those of the spring of 1983.

3 - It is estimated that substantial subdivision impact has a probability of 5% if groundwater levels dramatically rise above those expected.

4 - Adverse impact on the water storage tank is estimated to have a probability of less than 5%.

5 - Remedial stability improvement measures could be taken to reduce the impact probabilities and increase safety.

INTRODUCTION

An evaluation of the landslide adjacent to the Canyon Cove #2 Subdivision, Salt Lake County, Utah is the subject of this report. The study was authorized and undertaken at the request of Mr. Jay L. Murphy, Wasatach Boulevard and Canyon Cove Company, Salt Lake City, Utah.

The Canyon Cove landslide was first noted in late April 1983 at the location shown in Figure 1. Movements of the landslide were measured and recorded from April 29, 1983 to October 19, 1983. During that period a total of approximately 1 3/4 feet of displacement was determined to have taken place at a point in the central area of the slide. Owing to a concern for safety and property damage in the adjacent Canyon Cove #2 Subdivision, Seegmiller International(SEEGMILLER) was retained by Wasatch Boulevard and Canyon Cove Company to assess the landslide stability. Central to the question of stability are three items to be addressed[1]:

1 - The limits of the run-out zone in the event a slide should occur under circumstances similar to those that existed during the spring of 1983.

2 - The limits of the run-out zone given the worst case scenario and its probability of occurring.

3 - The impact of each of the above events on the water storage tank east of lots 301 and 302.

The sources of information used in the investigation have been limited to surface reconnaissance, displacement data and a geophysical study. No subsurface exploration in the form of drilling or displacement measures was undertaken. Therefore, the analyses and conclusions should be regarded as preliminary in nature and not as the final word.

The report begins with an assessment of all available landslide data. Next, the displacement monitoring is discussed and displacement projections are made. A stability analysis is then undertaken including a back-analysis and an analysis of future movements. Pertinent conclusions complete the report. The details of the geophysical investigation are appended.

LANDSLIDE DATA

GEOMETRIC DESCRIPTION

Overview. The landslide measures approximately 1000 feet horizontally in the north-south direction and approximately 800 feet horizontally from crest to toe. The elevation differences from toe to crest varies from approximately 240 feet up to 425 feet. Typically, the landslide zone is on the order of 325 feet high.

Displacement Depth. The depth of displacement or depth of broken rock involved in the landslide has been the subject of a special geophysical study. The geophysical study was conducted by Cooksley Geophysics, Inc. of Redding, California during November 1983. The study involved the use of a geophysical technique known as seismic refraction. Details of the seismic method, its application and results, as applied to the Canyon Cove landslide, are presented in Appendix I of this report. The results of the geophysical study indicate that low velocity rock units consisting possibly of slide debris and weathered and fractured bedrock may exist up to depths on the order of 100 feet.

Landslide Volume. For purposes of the present study, it will be assumed that the entire slide has a depth of 100 feet. Such an assumption is on the conservative side as may be noted by examination of the cross section lines in the geophysical report. Using a 100 feet of depth and the limits of the slide as denoted by tension cracks, a volume of 1.4 million cubic meters was computed.

$1\ \text{FT}^3 = 0.0283\ \text{m}^3$ 40469,150

PREVIOUS MINING

Mining of clay materials at the base of the landslide area, in what is generally referred to as the Clay Pit, has occurred for some years past. The volume of clay materials removed is not known precisely, but indications[2] are that the volume would exceed several hundreds of thousands of tons. Mining was undertaken[3] with front-end loaders and no blasting was ever required or used.

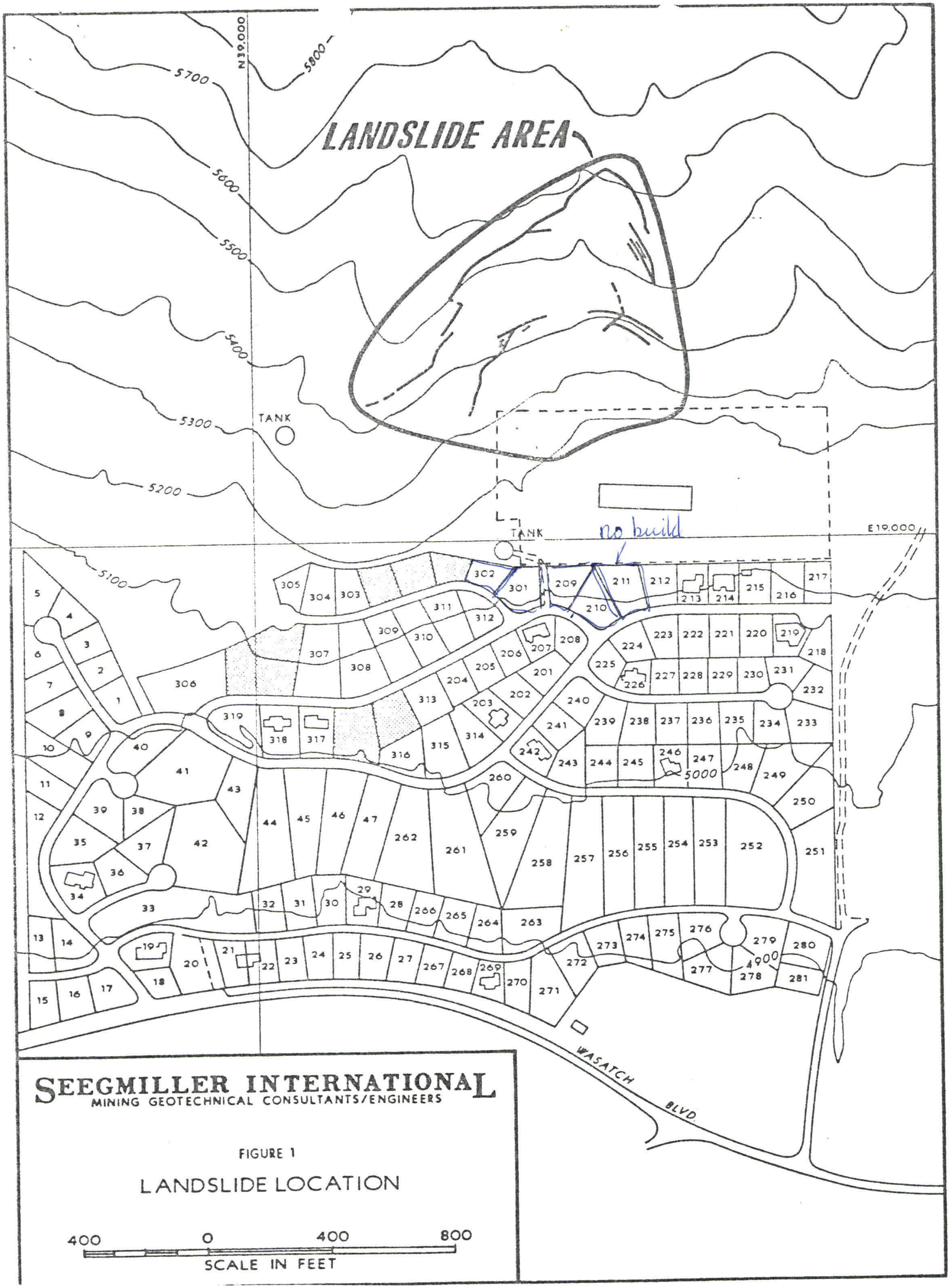

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FIGURE 1

LANDSLIDE LOCATION

Geology and Structure

The geology of the Clay Pit and landslide area consists of weak slates and argillites. A hard, strong quartzite, which together with the slates and argillites form the so-called[4] Big Cottonwood Series of stratigraphic units, is located on the ridge north of the Clay Pit. Portions of the tension cracks cut into the quartzite but, in general, the quartzite is offering end restraint and buttressing to the weak slates and argillites. The stratigraphic units all appear to generally strike approximately N 70° - 80° E and dip approximately 55° - 60° N. No pre-landslide crosscutting faults, per se, were observed, but displacements have occurred along the bedding in various areas in the slates and argillites. The contacts between the quartzites and the slate-argillites do not always appear stratigraphic and structural movements are suspected in a number of places. Jointing in the argillites and slates is not definable, but at least two sets are observable in the quartzites. Major sub-vertical tension cracks outline the major zone of landslide displacement. In addition, major tension cracks cross the landslide near the 5400 foot elevation and essentially divide the moving mass into upper and lower zones.

Groundwater

A spring exists at the base of the landslide near the water storage tank. Other, although minor, water seeps and wet areas in the slide zone were noted. Such springs, seeps and wet areas are indicative of subsurface groundwater pressurization. The amount of groundwater is not the most important factor, but rather the pressurization which the groundwater is exerting upon the slope materials. Based on the site observations and previous experience with groundwater in unstable slopes, it is concluded that adverse groundwater pressurization has strongly affected the stability of the general landslide area.

Rock Mass Strength

The general strength of the near surface slate-argillite materials is rated as very, very low. The fact that clay was mined at the site is indicative of weak, low shear resistant materials existing at the base of the landslide. Such clayey materials offer little resistance to sliding and commonly are associated with slope failures. Because such materials exist at the base of the landslide, it is very likely that they extend into and along the basal shear plane. The geophysical study indicated velocity contrasts of more than fourfold between materials designated slide debris and harder, stronger bedrock. When all available data is considered, the landslide mass must be presumed to consist almost totally of very weak, broken slate-argillite materials with higher than average clay content. Some of the harder quartzites along the northern landslide boundary have been displaced and form a portion of the landslide mass., However, these quartzites are minor in extent and are believed to actually provide some shearing restraint and buttressing.

Slope Instability Causes

Direct Causes. The slope failure, or landslide, apparently[5] first moved sometime in April 1983, but tended to stabilize with most movement ceasing by July 1983. Based on the various landslide data, visual summaries of which are presented in Figures 2 and 3, the landslide was a result of a number of factors. Groundwater is believed to be the most important of these factors and it was probably the triggering mechanism. The fact that the major movement occurred in the early spring of 1983, when groundwater levels and surface runoff were believed higher than usual, and the fact that groundwater still exists in the instability area are strong evidence that it actually triggered the movement. The existence of the mining operation is also a major factor in the cause of the slope instability. The fact that the main tension crack is located directly in back of the Clay Pit area, and approximately parallels the general shape of the mining zone, is strong evidence to suggest that the earth is undergoing a stress readjustment. The readjustment is in response to the creation of the Clay Pit and the removal of toe support materials. Another factor is that the geologic strata are oriented such that sliding could occur, at least in part, along weak bedding planes in slate-argillite on the south side of the moving zone. Further, the general rock mass strength is such that a fairly weak hillside initially existed. The weak mass was forced into stress disequilibrium by mining and then the rising groundwater pressurization caused a loss of effective stress, thus triggering the initial March 1983 movement.

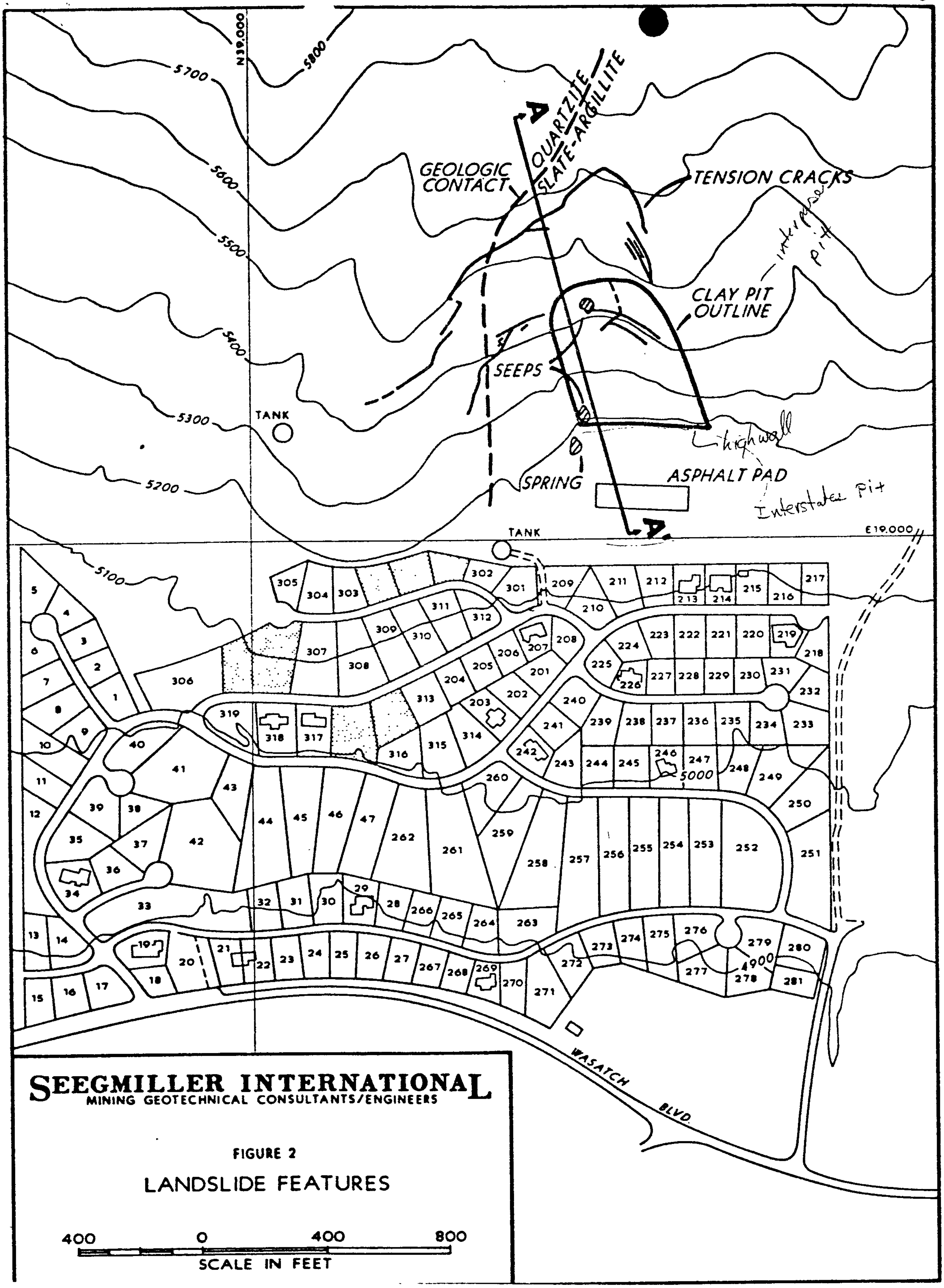

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FIGURE 2

LANDSLIDE FEATURES

400 0 400 800
SCALE IN FEET

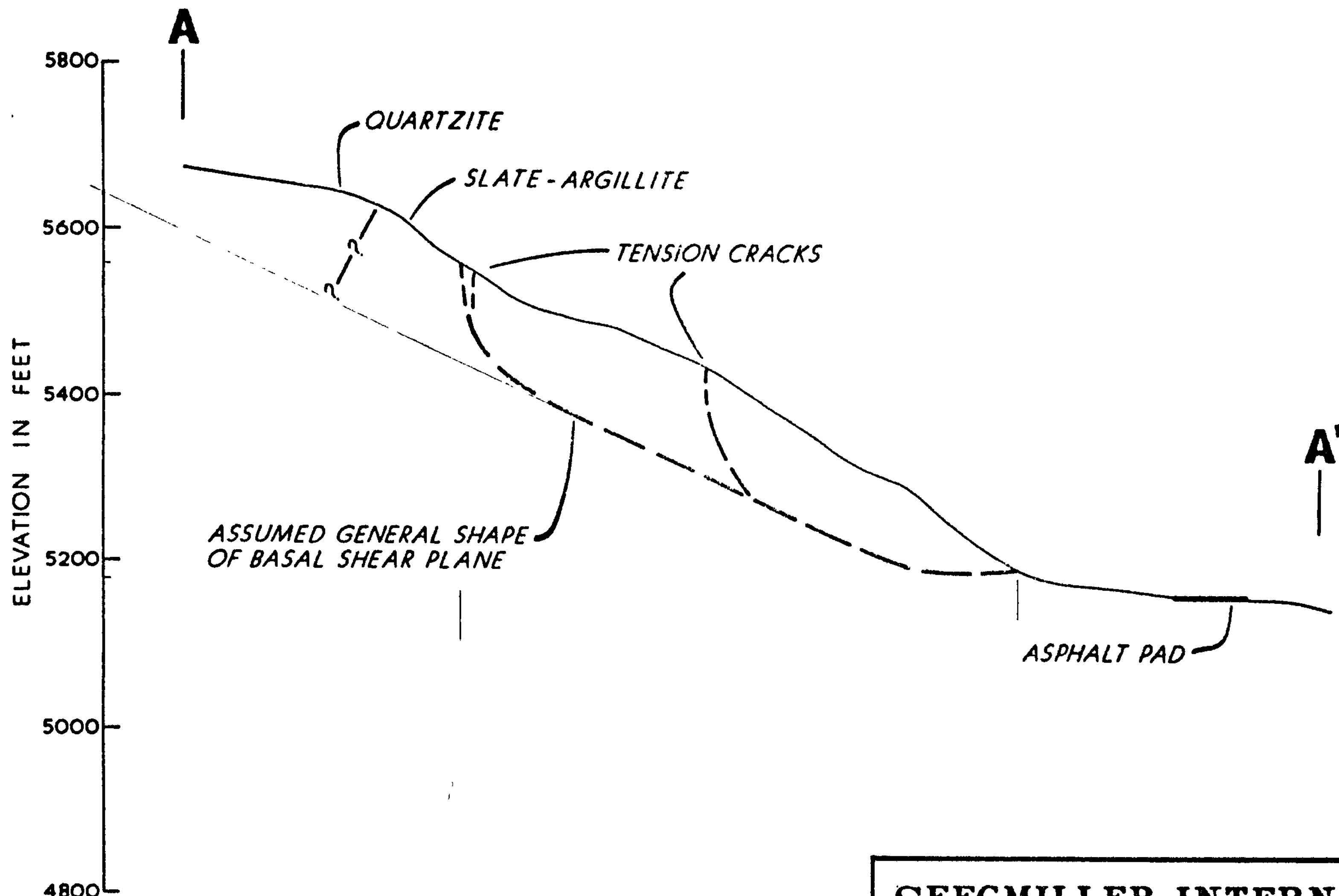

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FIGURE 3
LANDSLIDE CROSS-SECTION A-A'

400 0 200 400
SCALE IN FEET

Seismic Factors. The Canyon Cove area, as well as the entire Wasatch Front, is rated[6] as a Zone 3 seismic coefficient area. Such a rating is similar to the rating given the coastal portions of California and is the highest seismic coefficient rating that is used in the U.S.A. Should an earthquake of large Richter magnitude occur in the Salt Lake County area, it would probably have an adverse effect on the stability of the Canyon Cove landslide. However, if such a large magnitude earthquake did occur, it is likely that the stability of many areas adjacent to the Wasatch Front would be adversely effected. The existing Canyon Cove landslide is not believed to have been affected by any recent seismic events including the Richter magnitude 4.25 earthquake which occurred on October 8, 1983. That earthquake, which had its epicenter approximately two miles south of the Salt Lake International Airport, was the largest[7] magnitude earthquake to occur in Utah in 1983. A site visit to the Canyon Cove area subsequent to the October 8, 1983 event did not reveal any obvious effects relative to slope displacement.

DISPLACEMENT MONITORING

Overview

Following the discovery of the Canyon Cove landslide by the U.S.D.A. Forest Service on or about April 28, 1983, the Engineering Division of the Public Works Department of Salt Lake County began surveying a series of some sixteen points in and adjacent to the instability area. The locations of these points are as shown in Figure 4. The first survey data were collected on April 29, 1983 and the last were obtained on October 19, 1983.

Displacement Magnitudes

Cummulative Displacement. The Salt Lake County survey data[8] were made available to SEEGMILLER in late August 1983. The data were analyzed and it was determined that the point showing the largest amount of movement was Point "B". In landslide displacement monitoring, the point showing the greatest movement is generally

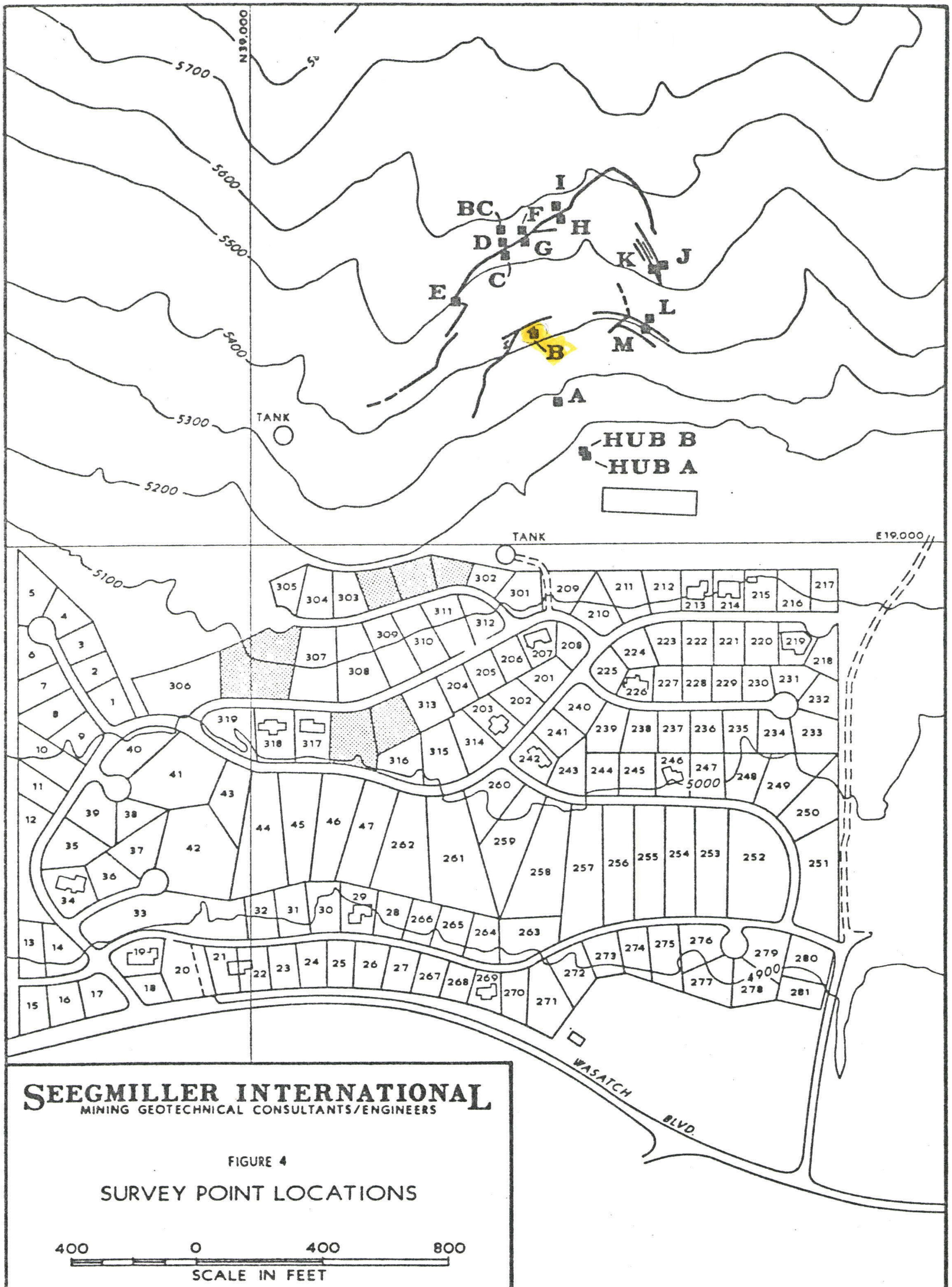

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FIGURE 4

SURVEY POINT LOCATIONS

400 0 400 800
SCALE IN FEET

the most likely point to first catastrophically displace. Therefore, Point "B" was selected for further displacement analysis. The survey data, when received, consisted of [1] horizontal east-west, [2] horizontal north-south and [3] vertical displacement values. These data were then combined to determine an overall displacement magnitude and displacement vector or direction. The overall displacement magnitude was approximately 1.61 feet for the 173 days during which Salt Lake County performed displacement monitoring. The direction of overall movement was S 74.6° W at an angle of 15.9° below horizontal. The displacement magnitudes serve as a measurement of the stability of a landslide and, as such, they are typically plotted for visual analysis. A common method for plotting the data is to plot cummulative displacement versus time. For Point "B" such a plot is shown in Figure 5. The total cummulative displacement magnitude is 1.77 feet and represents the summation of each individual movement occurring between surveying dates. Owing to the fact that such movements were not each in the overall displacement direction, their summation is 1.77 feet which is greater than the overall absolute displacement from the first survey date to the last survey date of 1.61 feet. In other words the shortest distance between two points is a straight line and that is less than a cummulative distance of many intermediate points, which do not lie on the straight line. The plot shown in Figure 5 indicates that movement of Point "B" has been dramatically lessening since late June 1983 and has shown very little movement from late August 1983 to late October 1983.

Velocity. Another method of ascertaining the stability of a landslide is to plot velocity versus time and visually assess the results. Such a plot has been made for Point "B" and is presented in Figure 6. As may be noted, the velocity was quite erratic until late June 1983. Since that time, the velocity has generally lessened and was very close to zero during the period August 19 - October 19, 1983.

DISPLACEMENT PROJECTIONS

Present Status. Based on the displacement data plotted in Figures 5 and 6 and assuming that Point "B" is a representative point for the entire landslide, it would not appear that any adverse movements are occurring as of October 19, 1983. The cummulative displacement has levelled to a degree that indicates continued stability. The velocity has settled down and no erratic

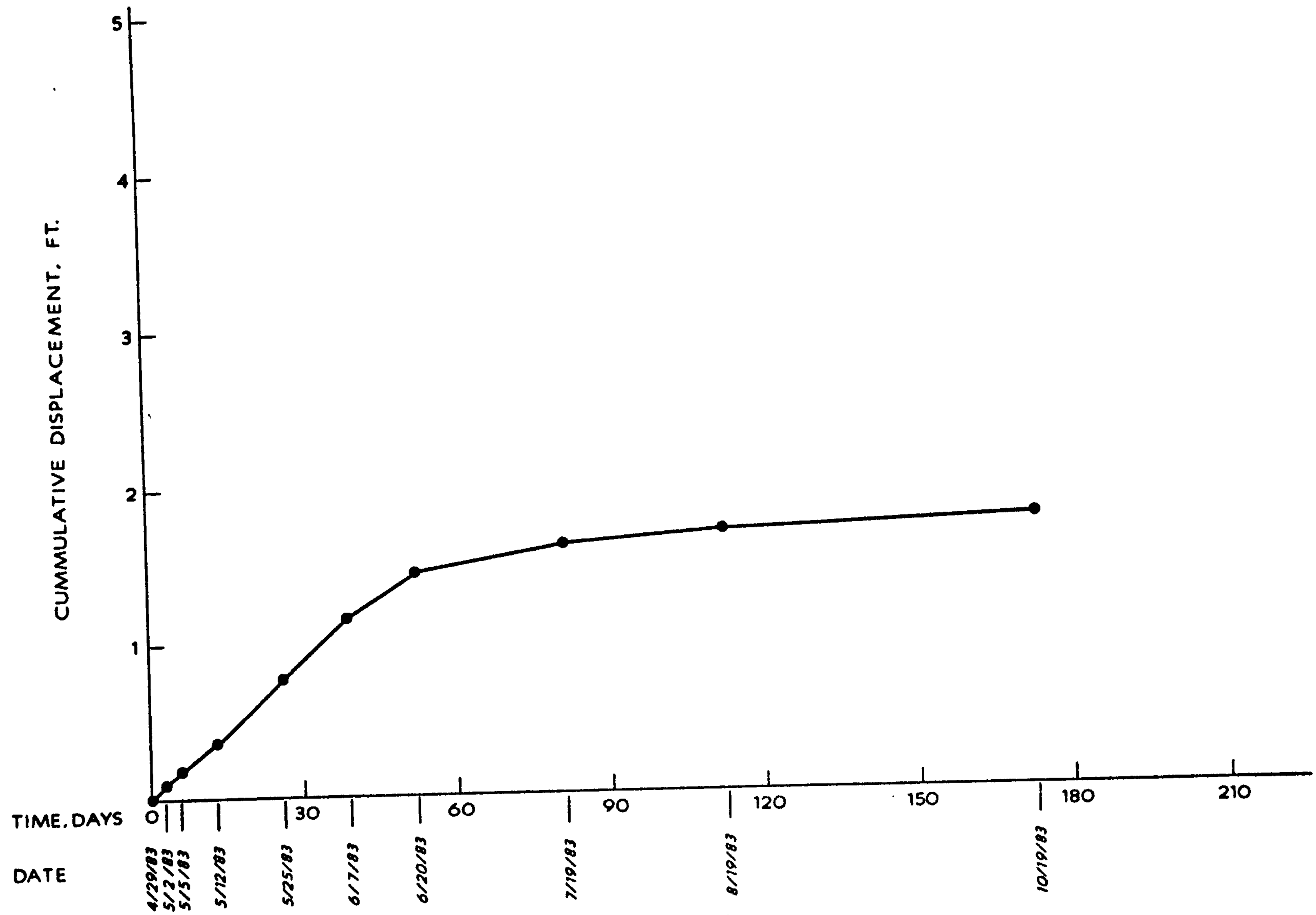

FIGURE 5

CUMMULATIVE DISPLACEMENT VERSUS TIME
CANYON COVE - POINT "B"

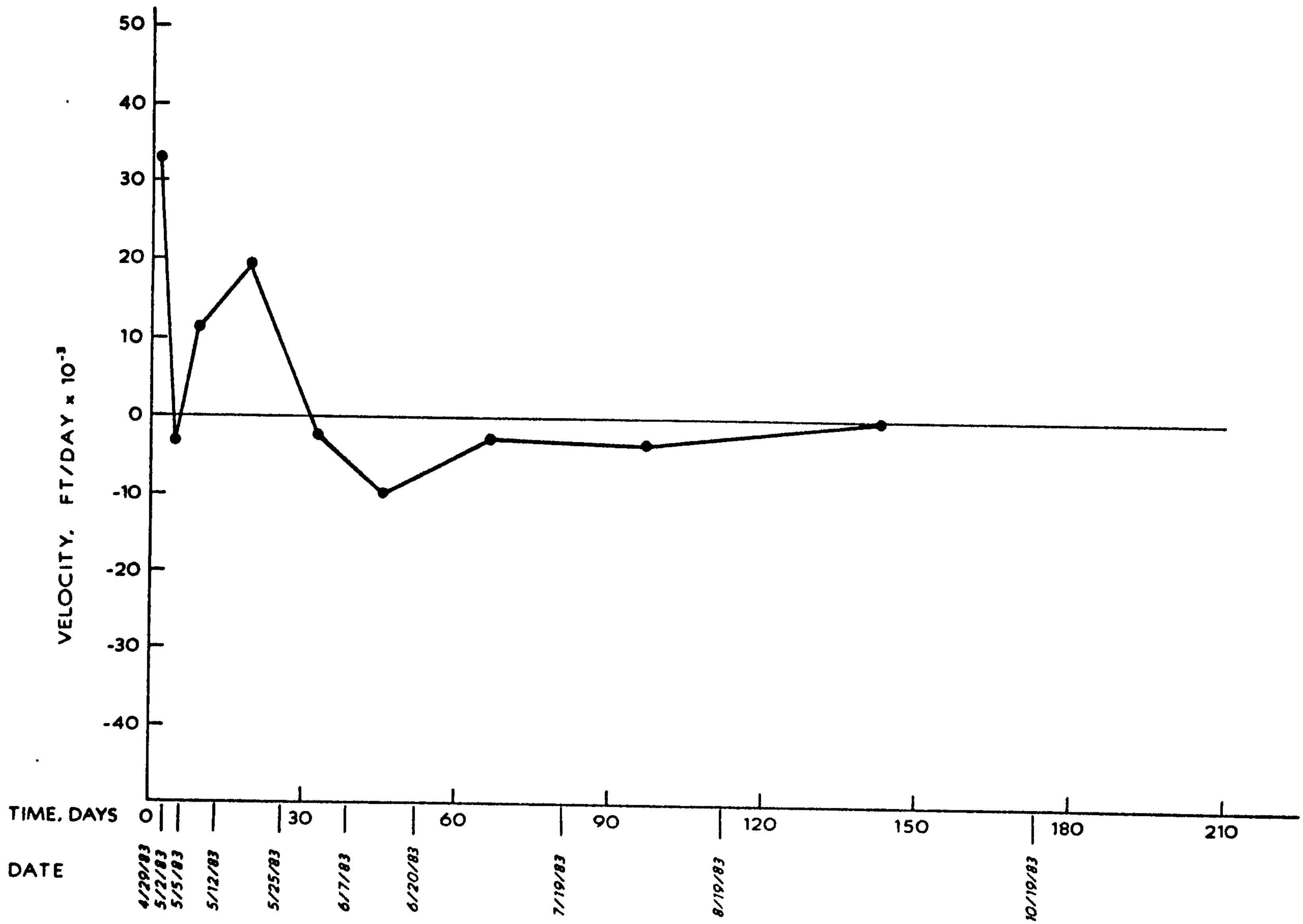

FIGURE 6

VELOCITY VERSUS TIME
CANYON COVE - POINT "B"

movements have recently occurred. There is good reason to foresee continued stability, if all adverse factors relating to movement do not change.

Future Displacements. Potential future movements should be entirely a function of the groundwater pressurization. Should the pressurization remain at similar levels to those existing during July - October, 1983 little or no further movement is likely. Should the pressurization increase to levels similar to those presumed to have occurred during April - May, 1983, additional movement and a velocity increase is highly probable. Should the pressurization increase to levels significantly higher than those during the spring of 1983, catastrophic landslide failure may become highly probable.

STABILITY ANALYSIS

PRESENT FAILURE BACK-ANALYSIS

Failure Mode. The Canyon Cove landslide is characterized by numerous crown tension cracks, but little evidence of toe displacement. Further, the landslide mass appears to be composed of weak, broken rock and soil with little integrity as a mass. Such characteristics are common for a rotational shear failure having a main basal shear surface as well as other internal shear surfaces.

Analysis Methods. In order to complete a back-analysis of the existing landslide and determine the possible characteristics at the time of failure, an analysis method, based on the failure mode, must be selected. The analysis method that will be used for the Canyon Cove landslide is known as the Hoek[9] method. The method is relatively straightforward, requires a minimum of assumptions and is fairly easy for a trained person to use. The basic premise of the method is that the forces tending to cause failure in a slope are balanced by the forces tending to resist failure at a safety factor of 1.00. If the safety factor is greater than 1.00, the slope is not failing. In most civil construction projects, a safety factor of 1.50 is the minimum acceptable safety factor for proceeding with construction. If the safety factor is less than 1.00, the slope is failing or will probably fail during construction.

Analysis Results. For purposes of the back-analysis it will be assumed that the cross section shown in Figure 3 is a typical cross section for the landslide. Other assumptions at the time of initial failure in the spring of 1983 include [1] a groundwater condition approximately equivalent to being half-saturated, [2] a material unit weight of 155 pcf and [3] a safety factor of 1.00. Using these assumptions in the Hoek method would allow the relationship of rock mass shear strength in terms of sliding friction angle and cohesion shown in Figure 7 to be constructed. For the Canyon Cove landslide the values of sliding friction angle(ϕ) and cohesion(C), most nearly characteristic of the basal shear plane, are believed to be $\phi = 25°$ and C = 2700 psf. These shear strength values may now be used to further investigate the landslide for stability under other groundwater pressurization conditions. A summary of safety factor magnitudes for various groundwater pressurization conditions for the landslide is shown in Figure 8. This figure dramatically illustrates the lessening of the safety factor that may be expected as the groundwater pressurization increases to a point near or at full saturation. The landslide is estimated to have a safety factor of 1.24 under the best conditions when it would be essentially dry. Under the worst conditions of full saturation the safety factor could theoretically drop to as low as 0.87. It should be understood that when the safety factor drops slightly below a value of 1.00, the landslide theoretically begins to move. It will continue to move as long as the pressurization level remains constant. An increase in the pressurization level will cause the landslide to move with increased velocity. Should the pressurization level rapidly increase in a very short time, the landslide could catastrophically fail. If the pressurization level were to dramatically increase to full saturation or nearly full saturation in a matter of hours, the landslide could become fully water mobilized and effectively turn into a mudslide. Such complete saturation may only occur during an intense rainstorm such as during a rainstorm with a probable maximum of ten inches in six hours. Such a probable maximum is the rating[10] by the U. S. Bureau for the Wasatch Front area. The one percent probability six hour rainfall for the Wasatch Front area is 2.5 inches.

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FUTURE INSTABILITY

Groundwater - Similar to Spring 1983. Should groundwater conditions similar to those which prevailed during the spring of 1983 again occur in the Canyon Cove landslide, further slope

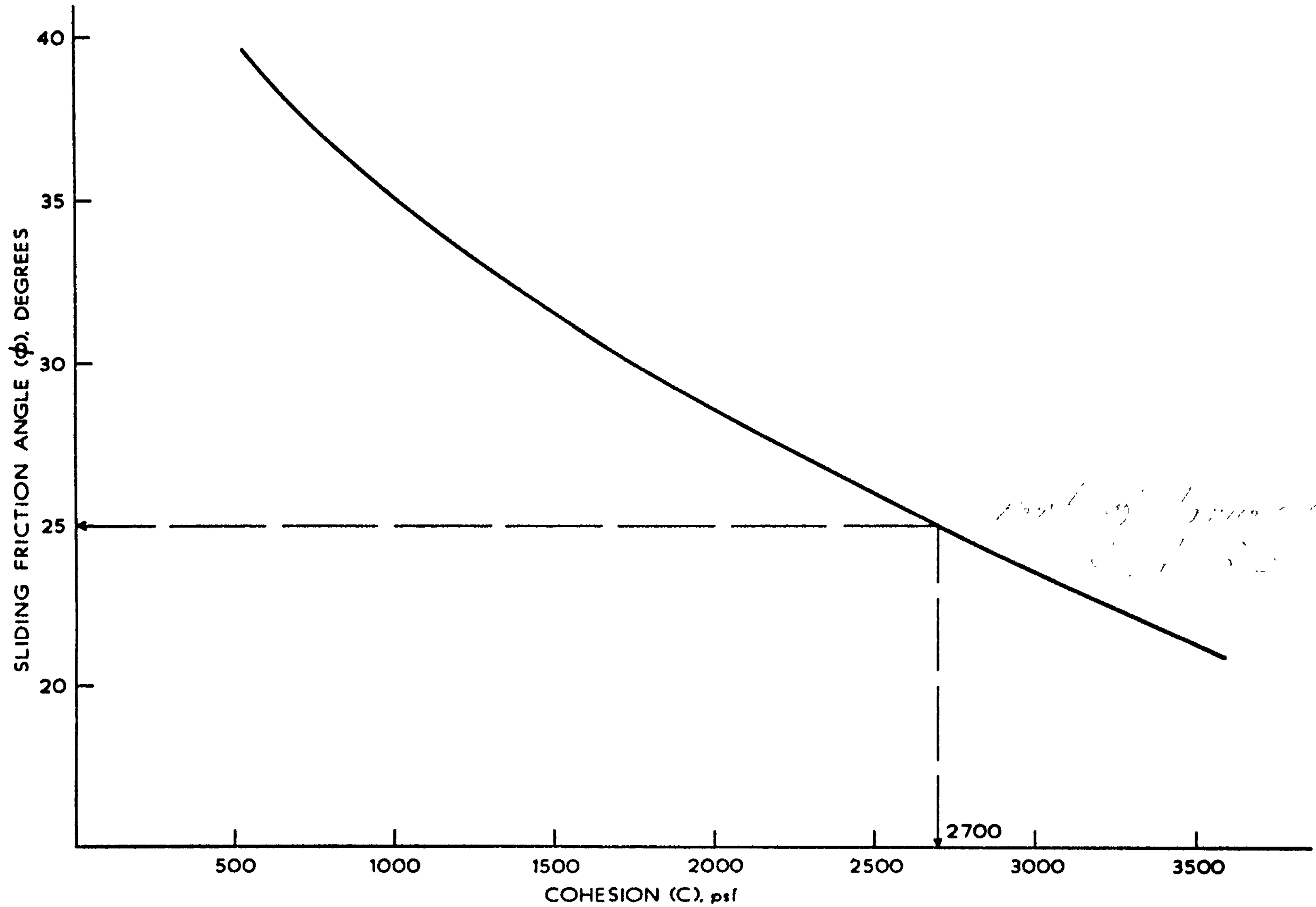


FIGURE 7

ESTIMATED RELATIONSHIP

SLIDING FRICTION ANGLE AND COHESION

CANYON COVE LANDSLIDE

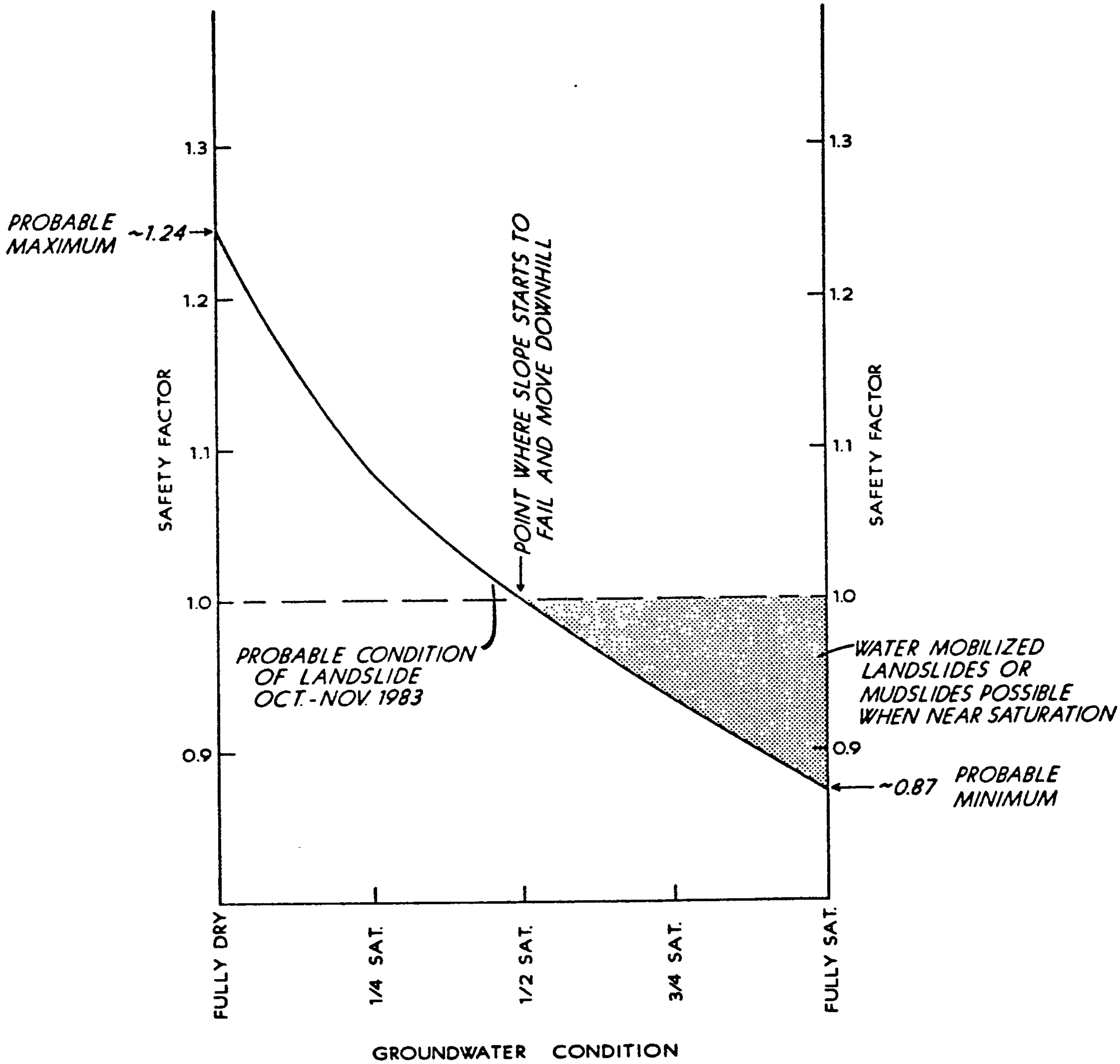
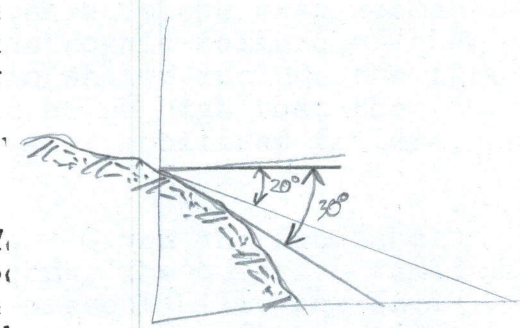


FIGURE 8

ESTIMATED RELATIONSHIP
SAFETY FACTOR AND GROUNDWATER
CANYON COVE LANDSLIDE

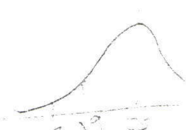
displacements are expected. The additional movements will probably be at least as great as those experienced during 1983 and quite possibly exceed an additional two feet. The velocities are expected to again become erratic and show signs of great instability. Catastrophic failure may o

Groundwater - Worst Scenario. Unde
the groundwater pressurization would inc
would greatly magnify and ultimately cat
landslide would occur. The worst scenar
that the groundwater pressurization coul
landslide mass could be saturated and a
or mudslide could occur.



Run-Out Analysis: Typical Landslid
a catastrophic landslide failure could o
as to how far in front of the toe of the
ing material could reach. To estimate t
mass, the concepts of Scheidegger[11] and (
These concepts pertain to the actual run-
waste rock dumps that have been documente
natural slopes the run-out angle is a fun
landslide in terms of volume. The run-out angle is defined as the angle below horizontal that the landslide will reach when measured at the breakaway point as shown in Figure 9. The volume of the Canyon Cove landslide was computed to be approximately 1.4 million cubic meters and using the Scheidegger criteria, a mean run-out angle of approximately 25° was determined. The standard deviation of the run-out angle was determined to be approximately ±5°. Assuming that the run-out angle values are part of a normal statistical distribution, the probability of not exceeding any particular run-out limit may be determined. For a 90% probability the run-out angle is determined to be greater than approximately 19°. For a 95% probability the run-out angle will be greater than 17°. In other words, three run-out magnitudes have been established. First, the most probable run-out limit is 25°. Secondly, there is a 90% probability that, if a landslide occurs, the run-out angle will be greater than 19°. Thirdly, given the fact that a landslide does occur, there is a 95% probability that the run-out limit will occur within a zone described by a 17° run-out angle. These magnitudes may be used to estimate the limits that the Canyon Cove landslide will reach should it fail. It should be noted that the concepts used to produce these run-out limits assume a landslide that is not water mobilized. It is tacitly assumed that the landslide will be induced by groundwater pressurization, but that the groundwater levels will not be so high that complete slope saturation and mudflow conditions prevail. The estimated run-out limits for the most likely

mean = 25°



the larger the run-out angle the smaller the sl

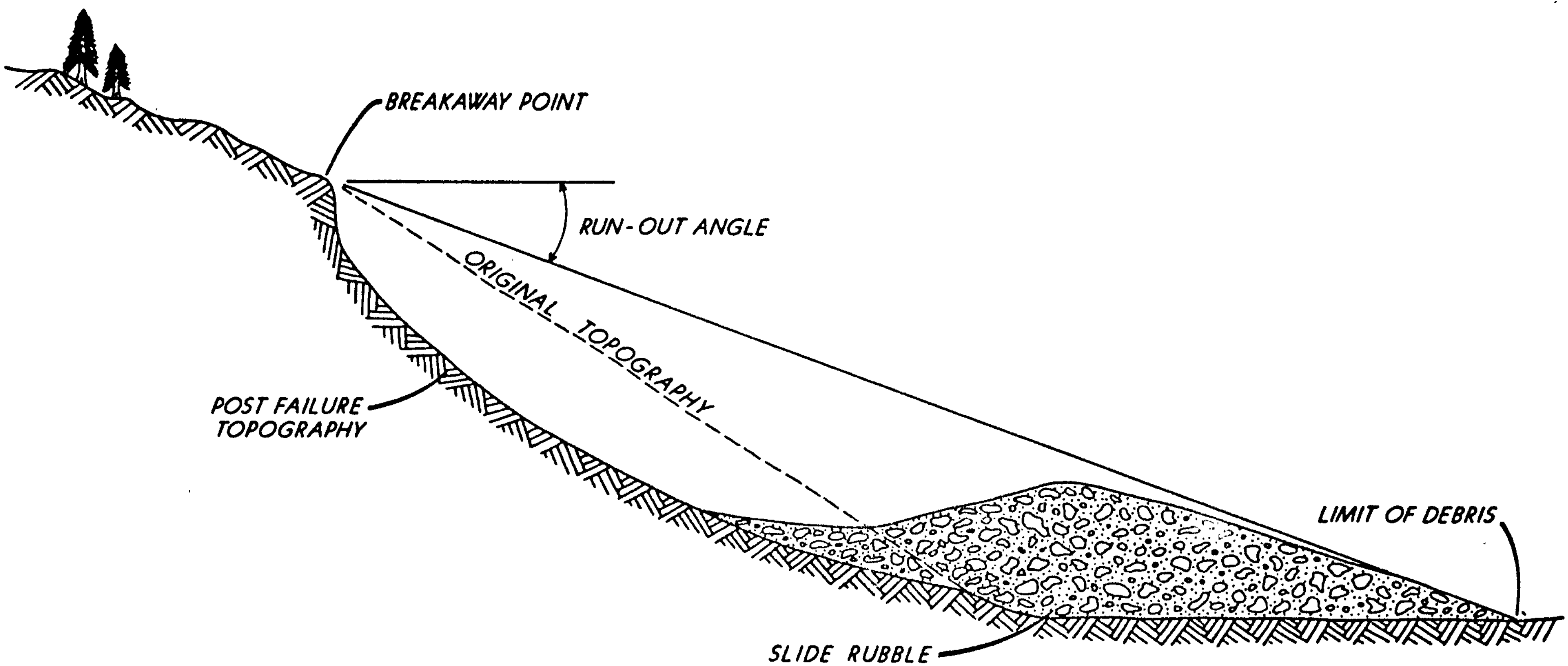


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FIGURE 9
RUN-OUT ANGLE DEFINITION

conditions and the 90% and 95% probability conditions are shown in Figure 10. If greater probabilities are examined, the limits increase in the general southwest direction. These limits may be taken as the run-out limits for a slide occurring under circumstances similar to those that existed during the spring of 1983. The impact of this event on the water storage tank east of lots 301 and 302 may not be too bad because the tank is toward the side of the main run-out zone. The probability of the run-out area extending to the edge of the tank is estimated to be approximately 20%. However, the forces involved in landslides are known to be large and the exact limits of the run-out zone are not always predictable. Therefore, a cautious approach is recommended.

Run-Out Analysis: Mudslide. Should the groundwater pressurization increase dramatically in a very short period of time, such as a few hours, the Canyon Cove landslide could become totally water mobilized and fail as a mudflow or mudslide. The criteria for determining the run-out limits has not been well-established by past mudslide documentation. However, an empirical method[13] which states that the downslope impact area extends a distance equal to the height of the slope for each 5% natural ground slope below the toe, could be used. This criteria was developed for mine waste embankments, and as such, may not be totally applicable to the Canyon Cove landslide. However, such a criteria could give an indication of the worst condition that might prevail if the landslide became a mudslide. Applying the empirical criteria to the Canyon Cove landslide yields the probable impact limit shown in Figure 11. This impact limit may be treated as the most probable limit of the run-out zone given the worst case scenario. The impact on the water storage tank east of lots 301 and 302 can only be estimated. Mudflows tend to move around stiff objects as opposed to pushing them forward. Owing to the fact that the tank is on the north edge of the landslide and the central mudflow impact area, it is not expected to be moved from its foundation. However, as has been previously stated, such events are difficult to predict and caution should be exercised.

Probability of Future Events. The run-out analyses have established the limits at which various landslide/mudslide events may occur. The probable limits assume that such events will occur. The probabilities stated are not probabilities of actually happening, they are probabilities of what the limits will be if they do happen. The probabilities of what will actually happen may only be estimated based on past data and experience. For the Canyon Cove landslide it is estimated that there is a 50-75%

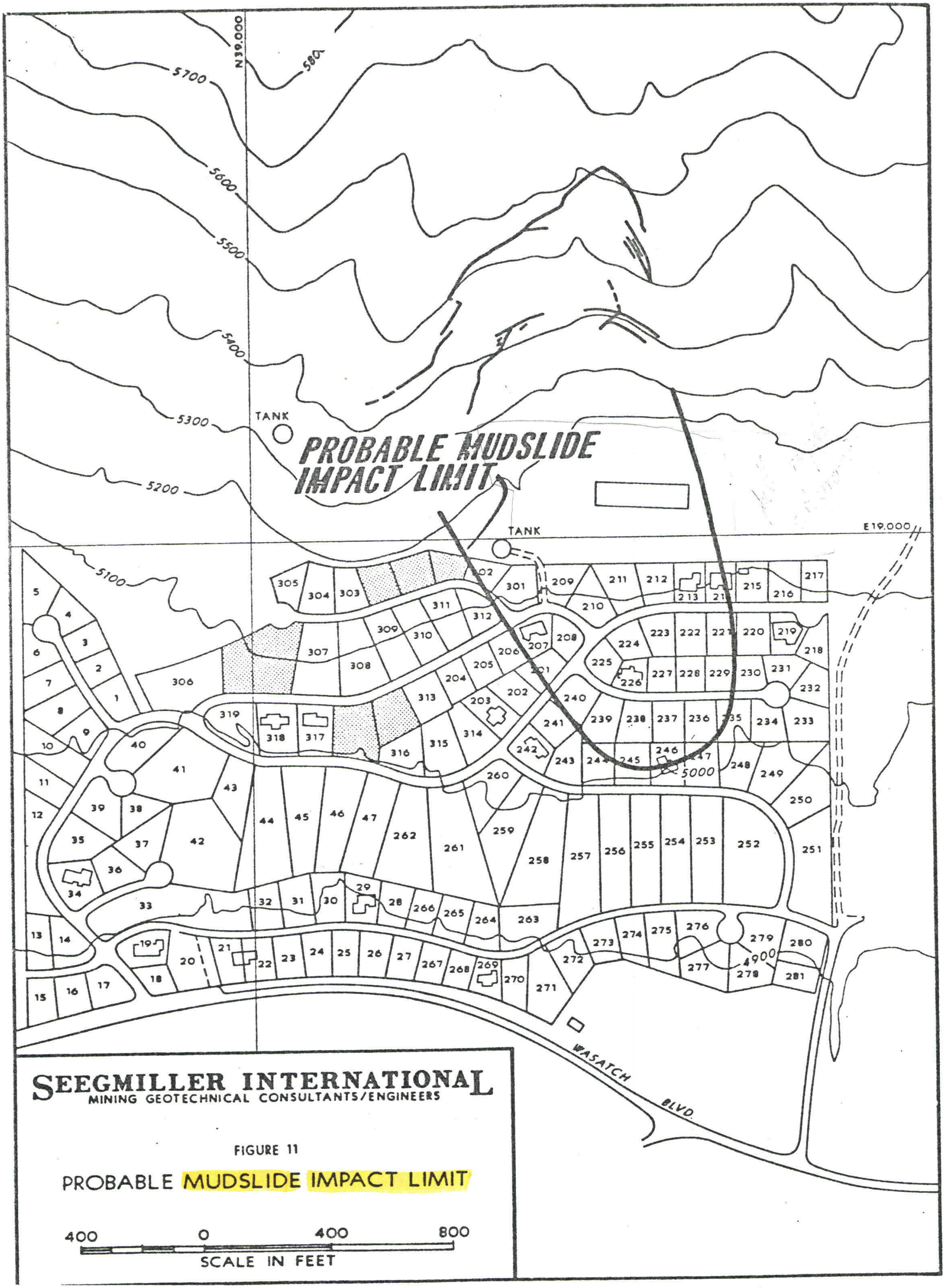

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FIGURE 11

PROBABLE MUDSLIDE IMPACT LIMIT

400 0 400 800
SCALE IN FEET

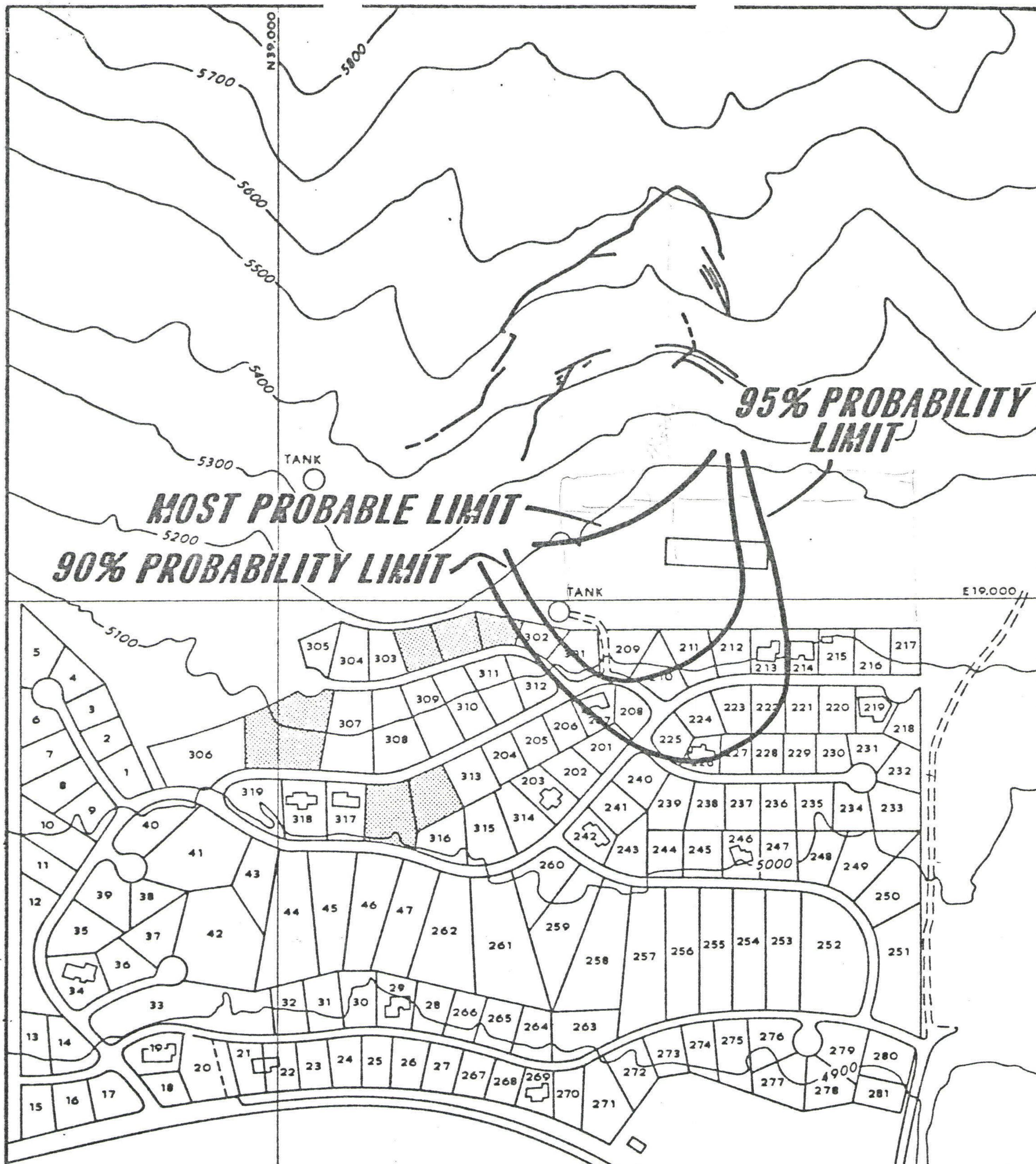

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FIGURE 10

LANDSLIDE RUN-OUT LIMITS

400 0 400 800

SCALE IN FEET

50-75%

chance that the groundwater conditions will again reach the pressurization levels in the spring of 1984 that they did during the spring of 1983. Consequently, there would be an estimated probability of up to 75% that the slide will again displace as it has done previously. On the other hand, it is estimated that there is only a 10% probability that the landslide will displace catastrophically. The probability that the landslide will become a mudslide and reach the projected impact limits is estimated to be on the order of 5%.

CONCLUSIONS

Based on the available stability data and the analyses conducted, the following are concluded relative to the stability of the Canyon Cove landslide:

1 - The landslide will likely displace as groundwater pressurization increases during the sring of 1984.

2 - The probability of a catastrophic failure occurring is estimated to be on the order of 10% under similar weather conditions as those which prevailed during the spring of 1983.

Landslide

3 - Should groundwater levels dramatically rise beyond the expected levels, the Canyon Cove #2 Subdivision could be impacted substantially, but such impacting is estimated to have only approximately a 5% probability.

MUD SLIDE

4 - The impact of slope failure on the water storage tank east of lots 301 and 302 could be adverse and cause it to displace from its foundation. However, the probability of such an event, under conditions prevailing during the spring of 1983, is a function of the probability of a catastrophic slope failure (estimated to be 10%) and the probability of the run-out limit reaching the tank(estimated

to be 20%). Therefore, it would appear that adverse impact of a landslide on the water storage tank may only be on the order of 2%. Under the worst case scenario the probability is still estimated to be less than 5%.

5 - Remedial stability improvement measures may be taken to lessen the impact probabilities and ensure greater safety to people and property.

see letter following "REFERENCES"

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APPENDIX I

GEOPHYSICAL INVESTIGATION

DETAILED REPORT

ENGINEERING GEOPHYSICAL INVESTIGATION OF SUBSURFACE GEOLOGIC CONDITIONS AT A SLOPE FAILURE SITE ABOVE THE CANYON COVE DISTRICT NEAR SALT LAKE CITY, UTAH

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ENGINEERING GEOPHYSICAL INVESTIGATION OF SUBSURFACE GEOLOGIC CONDITIONS AT A SLOPE FAILURE SITE ABOVE THE CANYON COVE DISTRICT NEAR SALT LAKE CITY, UTAH

PLATE 1
MISSING

INTRODUCTION

This report concerns an engineering geophysical investigation of a slope failure situated above the site of a residential development. This study consisted of executing two 1,000-foot long refraction seismic lines over the site as shown on Plate 1, Seismic Line Location Map. The field work was conducted on November 4, 5, and 6, 1983, and was computed the two weeks following.

This investigation was executed at the request of Seegmiller International, Salt Lake City, Utah, for the purpose of helping to define subsurface rock units at the site. Two parameters were measured. The first, seismic velocity, was used to tentatively identify the various soil and rock units and to assess their respective engineering properties. The second, depth, was measured in order to determine the configuration of the soil/rock contact and to define abnormally thick zones of low-velocity material which might be recent slide deposit.

The nature of the slide debris at this site had an unusually strong adverse affect on the propagation of seismic waves and thus resulted in some difficulty in the reduction and computing of the data. Because of this difficulty, the data and interpretation presented herein must be regarded as subject to some significant inaccuracy, but also adequately representing the nature and configuration of the geologic units for the purpose of at least a general or preliminary assessment of the slope stability conditions. If it is decided to proceed with further investigation, the seismic data gathering process can be improved from what was learned in this investigation.

This study indicates that there exist a potential for fairly deep-seated slope failure at the subject site. Further testing is needed to ascertain whether and when this potential has or will resolve into a landslide which will cause damage.

DATA ACQUISITION

Data acquisition and recording was carried out using a Geometrics ES 1210 engineering seismograph. This unit recorded twelve (12) channels of seismic data on a paper record. Timing for the ES 1210 is electronically controlled within the instrument.

Seismic vibrations were produced by detonating charges of dynamite in shot holes located at points along the survey line. Time of shot information was provided by a trigger circuit in the shot detonator. Detection of the seismic waves was provided by seismometers located at 50-foot intervals on the surface along the survey line. Seismic sensor locations are plotted on the survey line location map included in this report.

DATA ANALYSIS

The field records were inspected and the times of the first arrival of the refracted seismic waves at each sensor were recorded. The data was then plotted on a time-distance graph. Velocities along the lowermost layer on each traverse were computed by averaging the incremental travel times between individual sensors of waves traveling in opposite directions. A form of delay time, ray path analysis was used to compute depth of discontinuities.

INTERPRETATIONS

In this refraction seismic investigation, the subsurface is mapped in terms of velocity units. A velocity unit is a three-dimensional unit which, due to its elastic properties and density, propagates seismic waves at a characteristic velocity or in a characteristic velocity range. At least one velocity is present within a geological rock unit. Each zone of weathering or zone of fracturing within a given rock unit could constitute an additional velocity unit.

Conversely, when two rock units propagate seismic waves at the same velocity and are adjacent to each other, both units would be part of the same velocity unit. An example of this is probably where moderately consolidated slide debris and intensely weathered rock constitute the 2.5 fpms to 3.5 fpms velocity unit. The following geologic interpretations are obtained from the seismic refraction sections accompanying this report. (See Plates 2 and 3.)

The scope of this study did not include any detailed geologic mapping, photo interpretations or an in-depth field study of petrology and stratigraphy of the site. Interpretations are based upon the seismic data acquired and information provided by Seegmiller International.

In the interpretation of seismic data, the geological setting is of major importance. The contact between soil and rock strata is ideally defined on a seismic profile as an abrupt change in velocities. Actually a geologic contact is often a gradational change in physical properties.

At least six rock types are identifiable, in an engineering sense, from the seismic velocity data. These are as follows:

Seismic Velocity*	Thickness**	Inferred Geologic Unit	
1.0 - 1.5	0 - 40	Unconsolidated surficial deposit and slide debris, might include intensely weathered bedrock.	ZONE I
1.5 - 2.5	0 - 65	Poorly consolidated surficial deposit and slide debris, might include intensely weathered bedrock.	ZONE I
2.5 - 3.5	0 - 100+	Intensely weathered and fractured bedrock, probably includes some moderately consolidated slide debris.	ZONE II
3.5 - 6.25	0 - 100+	Moderately weathered and fractured bedrock, the lower velocities denoting rock material which might be degrading to slide debris.	ZONE II
6.25 - 8.5		Moderately degraded bedrock, probably caused by fracturing and shearing.	
8.5 - 22.2		Massive bedrock consisting mainly of slate, argillite and quartzite of the Big Cottonwood Series of late Precambrian age.	

* in fpms (feet per millisecond).
** in feet.

Table 1. Tabulation correlating the seismic measurements with inferred geologic conditions.

As shown on the table above, the unstable rock and soil mass at the site is subdivided into two zones, Zone I and Zone II. Zone I is regarded as the less stable, being partly comprised of soil and rock which has moved since last winter. Zone I grades both vertically and horizontally into the more stable Zone II. (See Plates 4 through 7.)

One unexpected observation from the seismic sections is that the velocities measured in Zone II tends to be greater in the downhill direction then in the sidehill direction. Two reasons for this are offered as follows:

1) The lower velocity in the side hill direction is related to east-striking faults and fractures and is not affected by slope failure. This would indicate that Zone II might not be moving.

2) A significant component of movement in Zone II tends to be in the sidehill direction.

CONCLUSIONS

Generally, the seismic data indicates the following features in this area:

1) There exists a mantle of low velocity soil and rock units exceeding 100 feet in thickness over the slate, argillite and quartzite bedrock of the Big Cottonwood Series.

2) At the least, there have been shallow slides moving in the area during the past several months.

3) There exists in Zone I a rather significant potential for slope failure to depths ranging from a few feet to sixty (60) feet.

4) Although Zone II is more stable than Zone I, its potential for slope failure cannot be evaluated with the present data.